Electronics

for

B.Sc. Students

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Preface

This book of Electronics is written for B.Sc. students. It is hoped that its distinct approach and contents will meet the needs of the students. The overall plan for the book is both simple and logical.

The study of electronics is an essential part of the Physics, since the applications of modern electronics are widespread and are continually increasing. Today electronics touches the life of everybody in some ways daily.

This book presents fundamental principles of tubes, rectifiers, transistors, amplifiers, oscillators, and logic gates. The introductory material is followed by a series of chapters dealing with electronic theory. The theory and concepts have been stated clearly, simply and logically so that the student can readily grasp and understand them. Once the basic electronic circuits are understood, they can be shifted with confidence and understanding in many different applications.

Every effort has been made, with brevity and easy to follow format, to ensure that this book will have greatest usefulness to the student. I am grateful to my B.Sc. students of those Colleges where I taught, who gave me the incentive to write this book. Comments and suggestions are always welcomed for further improvement.

October 16, 2007. Ross Nazir Ullah

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Chapter-1

Introduction

1-1 Few Definitions

Electronics:

A branch of Physics, which deals with flow of charges (mostly electrons) through tubes and semiconductors.

Active elements:

Which are capable of delivering power to some external device; such as, voltage and current sources. Examples are, battery, power supply.

Passive elements:

Which are capable only of receiving power; they do not have any source within them. Several passive elements are able to store a finite amount of energy and then return it later to external elements. Examples are resistor, inductor, and capacitor.

Electrical network:

The interconnection of circuit elements (in any way) is called a network

Electric circuit:

If a network contains at least one closed path, then it is called a circuit.

Linear element:

A passive element that has a linear voltage current relationship; that is, current I flows in that element is proportional to voltage applied. Examples are resistor, inductor.

Linear circuit:

A circuit composed entirely of ideal sources and linear elements; that is the response is proportional to the source. Examples are $I \propto V$.

Ideal current source:

It is characterized by the current through the element, which is completely independent of the voltage across it. It is that source which supplies a constant current. It is non-existent in the real world.

Ideal voltage source:

It is characterized by a terminal voltage which is completely independent of the current through it. It is that source which supplies a constant voltage. in this case the internal resistance is very low. The ideal voltage source does not represent exactly any real physical device, because it could theoretically deliver an infinite amount of energy from its terminals.

Practical voltage source:

A low internal resistance (0.01 ohms) and the ideal voltage source.

Practical current source:

The ideal current source in parallel with an internal resistance.

1-2 Electrons Production

In electronics, we have to deal with the motion and production of electrons. Electrons are produced by different methods.

1. Thermionic Emission:

In metals there are some free electrons moving in the metal. When the temperature is raised their kinetic energy increases and they vibrate violently till they overcome the surface forces and get out of the metal.

2. Photoelectric Effect:

By this phenomenon a good number of substances chiefly metals under the influence of radiations such as γ-rays X-rays, ultraviolet rays and even visible light emits electrons.

3. Emission of electrons by applying a high field:

An anode is brought near the source of electrons (i.e. metal). Application of high potential difference between the two electrodes causes emission of electrons from the metal. This method is however avoided.

4. Secondary electron emission:

Bombard a beam of electrons on a metal surface, theses electrons will impart energy to the electrons of the metal and when the metal-electrons overcome threshold energy, they get out of the metal surface. This is secondary electron emission.

5. Electron emission by ionization:

In discharge tube the electrons constituting the cathode rays are produced by the process of ionization by collision under the action of a strong electric field.

[**Emission efficiency** is defined as the amount of current emitted in milli-amperes per watt.]

1-3 Types of thermionic emitters

1. Pure Tungsten:
Tungsten is superior to other emitters in ability to operate under adverse conditions. Its emission efficiency is not very high, even operated at temperatures 2550 K.

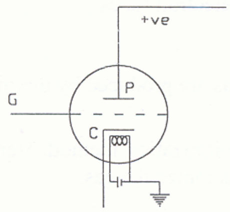
2. Thoriated Tungsten:
Thoriated-tungsten emitters consist of tungsten containing a reducing agent (ordinarily carbon and small quantity of thorium oxide). Such cathodes when properly activated given electron emission at temperatures of approximately 1900 K.

3. Oxide Coated Emitter:
The oxide-coated emitter consists of a mixture of barium and strontium oxides coated on the surface of a suitable metal, commonly nickel or nickel alloy. When properly prepared and activated such a surface will emit electrons profusely at the temperature of 1150 K.

1-4 Electrodes

There are generally three types of electrodes.

1. Cathode
2. Anode
3. Grid



1) Cathode:

Cathode emits electrons when it is heated to a high temperature say 700 K to 2500 K.

i) Directly heated cathode:

It is a filament of wire, which can be heated, so that it emits a stream of electrons when a current is passed directly through it from a (D.C. source) battery or cell.

ii) Indirectly heated cathode:

It is preferable to use an indirectly heated cathode in which the emitting surface is heated by a filament insulated from it. Its advantage is that it has a unipotential surface.

2) Anode:

Anode consists of a metal plate placed opposite to that of cathode. Tungsten and graphite are generally used, as they can with stand heavy bombardment and have greater emissive power. There is a cooling arrangement outside the tube to absorb the heat of the anode.

3) Grid:

It is interposed in between the cathode and the plate. It is in the form of a spiral of wire or a mesh surrounding the cathode. It exercises a much greater control on the flow of electrons than does the plate potential. Thus a small variation in the grid potential could be made to produce a much greater variation in the plate potential. The potential on the grid is –ve with respect to cathode. It affects the electrostatic field near the cathode and hence controls the number of electrons reading the plate.

1-5 Electron tubes

Following are two types of electron tubes.

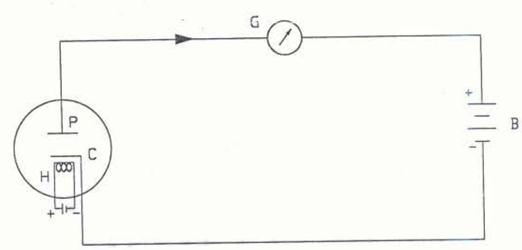
a) **Vacuum tubes**
In vacuum tubes electrons are produced by thermionic emission.

b) **Gas tubes**
In these tubes we use the ionization method. Here gases are in a partial state of ionization and highly moving electrons ionize the gas.

We will see some details of only three types of **high vacuum tubes**.

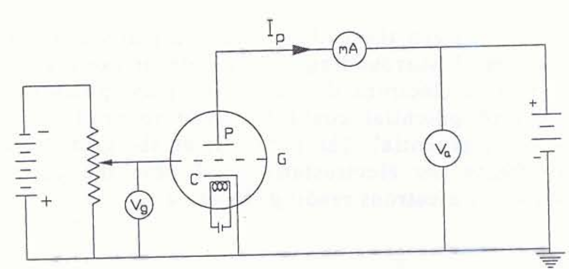
Diode:

A diode is a two-electrode vacuum tube containing a cathode that emits electrons by thermionic emission, surrounded by an anode.



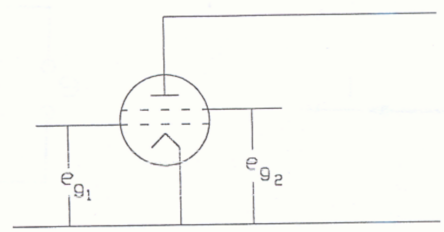
Triode:

A triode tube can be thought of as a diode to which there has been added a third electrode, i.e., grid located between the cathode and the plate for the purpose of controlling the flow of electrons to the plate and also minimizes the space charge effect.



Tetrode:

Tetrode is a four electrode tube with the introduction of screen grid. Potential of the screen grid is kept constant held +ve with respect to the cathode and it acts effectively as an electrostatic shield or screen between control grid and plate, and thereby reduces the capacitance between them to a very low value.



1-6 Three components of an electric circuit

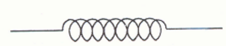
An electric circuit consists of one or more than one of three components: resistor, inductor, and capacitor.

Resistor:

A component included in the electric circuit because of its resistance.

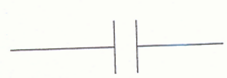
Inductor:

A device that produces a series of high voltage pulses by means of electromagnetic induction. It consists of a coil of wire with only a few turns, wound on an iron core and surrounded by another with many more turns. When the current in the first coil is interrupted suddenly, a large e.m.f. is induced in the second. A pulsed current in the first coil induces a large pulsed e.m.f. in the second.



Capacitor (or Electric condenser):

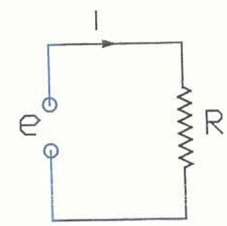
A combination of conducting plates separated by an insulator and used to store an electric charge.



1-7 Current versus voltage relation for R, I & C

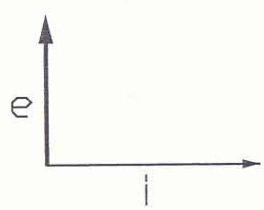
1. **Resistance R:**

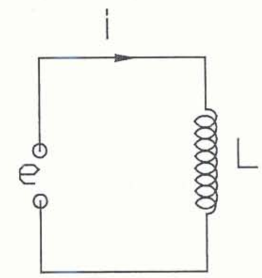
   When the voltage e acts across a resistance R, then we observe, i and e are in the same phase in a resistance.



2. **Inductance I:**

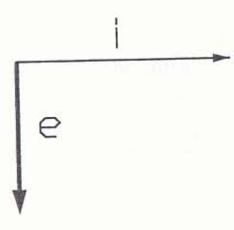
   When the voltage e acts across a pure inductance L, then we observe, i lags behind e by $\pi/2$ radians or 90^{o} in an inductance.

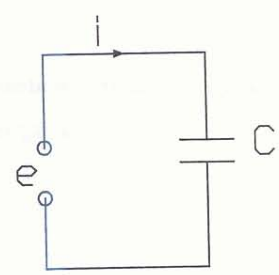




3. **Capacitance C:**

   When the voltage is applied across the pure capacity C, then we observe, i leads e by $\pi/2$ radians or 90^{o} in a capacity.





Chapter-2

Rectifiers

2-1 Definition & Applications

Rectifier is a device, which converts alternating current into unidirectional current by virtue of a characteristic permitting appreciable flow of current in one direction only.

A mechanical analogy is found in the trap valve of a reciprocating pump, which allows the flow of liquid in one direction but blocks its flow in the opposite direction.

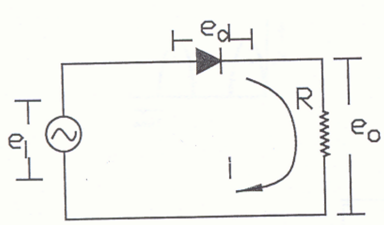
Most of the electronic devices require d.c. supply for their function, whereas the available electric supply is a.c. A rectifier circuit is usually used in electronic equipments to convert a.c. into d.c.

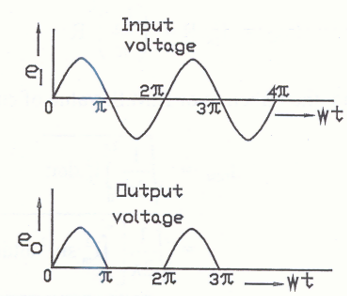
Applications: The production of direct current from alternating current source. for example in battery chargers, radio receiver, radio transmitter power supplies, X-ray machines, railway substations, electrolytic processes, and rectifier type alternating-current meters.

2-2 Half-wave Rectifier

A rectifier circuit in which only alternate half waves of the single phase ac input wave are effective in delivering unidirectional current to the load.

Figure below shows the circuit arrangement of half wave rectifier. A diode is used for rectification. The wave shapes of the input voltage e_i and output voltage e_o are shown.





During the positive half cycle, the diode is connected to the forward direction and a current is flowed through the resistance that serves as a load. The instantaneous value e_i equals voltage drop across the diode, which is (i x r) plus the voltage across the load (i x R).

During the negative half cycle, the diode is connected in the reverse direction and no current flows in the circuit. So the voltage across the load is zero. This type of rectifier circuit allows current to flow during the positive half cycles of e_i and blocks current during the negative half cycles. That's why this circuit is called half wave rectifier circuit.

2-3 Half-wave Rectifier—Mathematical Analysis

$e_b = E_m \sin \omega t$ [Please look Appendix A]

$$i_b = \frac{E_m \sin \omega t}{r_p + R} = I_m \sin \omega t \quad \text{for} \quad 0 < \omega t < \pi$$

$$\& \quad i_b = 0 \quad \text{for} \quad \pi < \omega t < 2\pi$$

so average or DC value of current

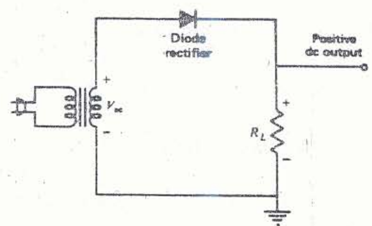
$$I_{av} = I_{DC} = \frac{1}{2\pi}\int_0^{\pi} I_m \sin \omega t d\omega t + \int_{\pi}^{2\pi} 0 d\omega t$$

$$= \frac{I_m}{2\pi}\left[-\cos \omega t\right]_0^{\pi} + 0 \qquad [\omega t = \theta]$$

$$= \frac{I_m}{2\pi}\left[-\cos(\pi) + \cos 0\right]$$

$$\text{or} \quad I_{DC} = \frac{I_m}{2\pi}\left[-(-1) + 1\right]$$

$$\text{or} \quad \boxed{I_{DC} = \frac{I_m}{\pi}}$$

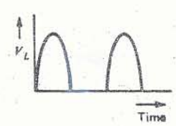


$$\& \quad E_{DC} = I_{DC} R$$

$$= \frac{I_m R}{\pi} \quad \text{or} \quad \boxed{E_{DC} = \frac{E_m}{\pi}}$$

and DC output power

$$P_{DC} = I_{DC}^2 R = \left(\frac{I_m}{\pi}\right)^2 R$$



And the effective or R.M.S. value of current

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i_b^2 . d\omega t}$$

$$= \sqrt{\frac{1}{2\pi}\left[\int_0^{\pi} I_m^2 \sin^2 \omega t d\omega t + \int_{\pi}^{2\pi} 0 . d\omega t\right]}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\left[\frac{1}{2}\omega t - \frac{1}{2}\sin 2\omega t\right]_0^{\pi} + 0} \qquad \left[\int \sin^2 x dx = \tfrac{1}{2} x - \tfrac{1}{2} \sin 2x\right]$$

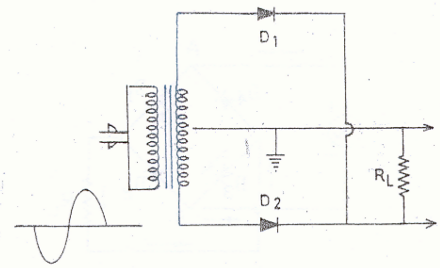
$$= \sqrt{\frac{I_m^2}{2\pi}\left[\left(\frac{1}{2}(\pi - \frac{1}{2}\sin 2\pi)\right) - \left(\frac{1}{2}(0) - \frac{1}{2}\sin 2(0)\right)\right]}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\left[\left(\frac{\pi}{2} - 0\right) - 0\right]}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\left(\frac{\pi}{2} - 0\right)} = \sqrt{\frac{I_m^2}{4}} \quad \text{so} \quad \boxed{I_{rms} = \frac{I_m}{2}}$$

2-4 Full Wave Rectifier—Mathematical Analysis

A rectifier circuit that rectifies both the positive and negative half-cycles of the single-phase a.c. input and delivers unidirectional current to the load.



$$e_{s1} = E_m \sin \omega t$$
$$e_{s2} = E_m \sin \omega t$$

If the two diodes are similar,
i.e. r_p is same for both, then

$$i_{b1} = \frac{E_m}{r_p + R} \sin \omega t = I_m \sin \omega t ,$$
for $0 < \omega t < \pi$, $i_{b2} = 0$

and $i_{b1} = 0$, $i_{b2} = \frac{-E_m}{r_p + R} \sin \omega t = - I_m \sin \omega t,$

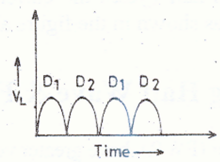
for $\pi < \omega t < 2\pi$

Between π and 2π, $\sin \omega t$ is negative and i_{b2} will be positive. So i_{b1} & i_{b2} are exactly similar. So integrating the current expression between 0 & π and dividing by the period π to get I_{DC} ,

So $I_{DC} = \frac{1}{\pi}\int_0^\pi I_m \sin \omega t d\omega t$

$$= \frac{I_m}{\pi}[-\cos\omega t]_0^\pi$$

$$= \frac{I_m}{\pi}[-(-1)+1]$$



i.e. $$\boxed{I_{DC} = \frac{2I_m}{\pi}}$$

& $E_{DC} = I_{DC} R = (2 I_m / \pi) R = 2E_m / \pi$ i.e. $E_{DC} = \frac{2E_m}{\pi}$

and DC output power

$$P_{DC} = I_{DC}^2 R = \left(\frac{2I_m}{\pi}\right)^2 R$$

& $$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i_b^2 d\omega t}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{\pi} i_{b1}^2 d\omega t + \int_\pi^{2\pi} i_{b2}^2 d\omega t}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{\pi} 2i_{b2}^2 d\omega t}$$

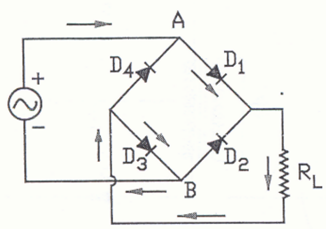
$$= \sqrt{\frac{2}{2\pi}\int_0^{\pi} I_m^2 \sin^2 \omega t d\omega t}$$ [<u>Please look Appendix A</u>]

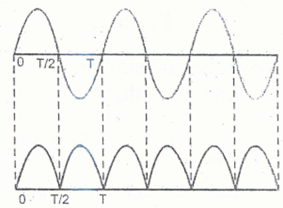
[Same mathematical steps as of last section]

so $$\boxed{I_{rms} = \frac{I_m}{\sqrt{2}}}$$

2-5 Full Wave Bridge Rectifier

In this rectifier circuit we use four diodes for full wave rectification.





This is commonly used circuit because it gives full wave rectification with ordinary transformer when point A is +ve with respect to B the diode D_1 is forward bias and current flows through D_1 , through R_L and then diode D_3 is forward bias so through D_3 and back to point B. A +ve voltage produced across resistor R_L . When point B is +ve with respect to A the diodes D_2 and D_4 are forward biased and current flows through point B, D_2 , R_L , D_4 and the point A. In both half cycles the current flows in the resistor R_L in same direction and produced an output as shown in the figure above.

2-6 Comparing Half Wave & Full Wave Rectifiers

1. Full wave rectifier (FWR) have greater voltage regulation than half wave rectifier (HWR).
   [For FWR, $E_{DC} = 2E_m/\pi$ & for HWR, $E_{DC} = E_m/\pi$]

2. The rectification efficiency is nearly double for full wave rectifier.
   [for FWR > 80 %, & for HWR < 41 %]

3. A filter will give more effective filtering for full wave rectifier and it costs less costly filters.
   [The ripple factor for FWR = 0.5 & for HWR = 1.2]

4. Half wave rectifier requires only one diode and is less costly than full wave rectifier.

5. Fundamental frequency of ripple is same as supply frequency for HWR but it is twice the supply frequency for full wave rectifier.

6. Full wave rectifier gives large load current as compared to half wave rectifier.
   [For FWR, $I_{rms} = \frac{I_m}{\sqrt{2}}$ & for HWR, $I_{rms} = \frac{I_m}{2}$]

7. Full wave rectifier gives greater power.
   [For FWR, DC output power = $\left(\frac{2I_m}{\pi}\right)^2 R$ & for HWR = $\left(\frac{I_m}{\pi}\right)^2 R$]

2-7 Important Aspects of Rectifier Circuits

Important properties of rectifiers are:

i) **Capacitor Filter**

To obtain a smooth DC output from a rectifier circuit capacitor filter is used.

During the conduction of the diode the capacitor charges and during the non conducting period the capacitor provide the current to the load resistor and discharge itself. The capacitor is charged by next conducting cycle. By use of suitable capacitor and resistor, we can obtain a very smooth DC output.

ii) **Rectification Efficiency (η)**

We define:

$$\text{Rectification Efficiency} = \frac{\text{D.C. power output}}{\text{A. C. power input}}$$

iii) **Ripple Factor (R.F.)**

We define:

$$\text{Ripple Factor} = \frac{\text{RMS value of a.c. component in the load}}{\text{D.C. components in the load}}$$

iv) **Voltage Regulation**

We define:

$$\text{Voltage Regulation} = \frac{\text{Output voltage at no load - Output voltage at full load}}{\text{Output voltage at full load}}$$

v) **Peak Inverse Voltage (PIV)**

It is the maximum reverse voltage, which the rectifier has to withstand during non-conducting period. It is equal to V_m in half wave rectifier, $2V_m$ in center tap full wave rectifier and V_m in full wave bridge rectifier.

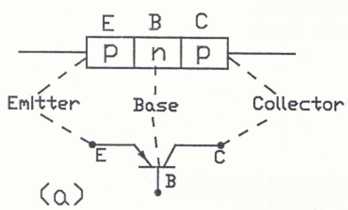
Chapter-3

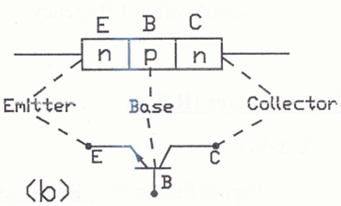
Transistors

3-1 Structure & Operation

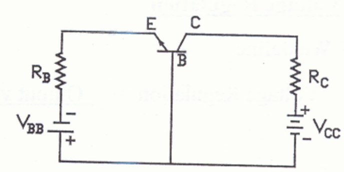
A transistor consists of a single crystal of germanium or silicon, which is grown in such a way that it has three regions.

There are two types of transistors—PNP and NPN. In PNP transistor, the central region is p-type, which is sandwiched between two n-type regions. In NPN transistor, the n-type central region is sandwiched between two p-type regions. The central region is known as base and the other two regions are called emitter and collector. Usually base is very thin, $\sim 10^{-6}$ m. the emitter and collector have greater concentration of impurity. The collector is comparatively larger than the emitter. The emitter has greater concentration of impurity as compared to the collector. We can say that a transistor is a combination of two back-to-back p-n junctions—emitter-base junction and collector-base junction.





For normal operation of the transistor, batteries V_{BB} and V_{CC} are connected in such a way that its emitter-base junction is forward biased and its collector-base junction is reverse biased. V_{CC} is of much higher value than V_{BB} . The polarities of the biasing batteries V_{BB} and V_{CC} are opposite in the two types of transistors. Usually NPN transistor is in common use.



We will use **NPN** transistor in the forthcoming discussion. And we will take the direction of ***conventional current*** instead of *electronic current.*

3-2 Working of a Transistor

Since a transistor has two PN junctions, there are four possible ways in which we can bias device. These conditions are:

a) Both junctions reverse biased: When both junctions are reverse biased, the device will have very large input and output resistances. The current through the device is practically zero and the device is said to be cut-off and acts as an open switch.

b) Both junctions forward biased : In this condition, both the junctions offer an easy flow of current. Input as well as output resistance is very low. The device is said to be in saturation and acts as a closed switch.

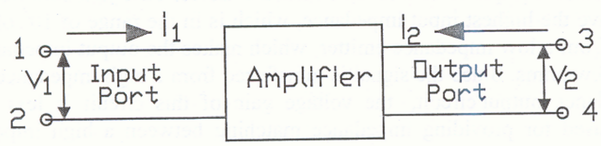
c) Emitter Base junction forward biased and collector base junction reverse biased : In this condition, the emitter base junction is small whereas collector-base junction has very large resistance. Since emitter-base junction acts as the input junction and collector-base junction acts as the output junction, the device will have a small input resistance and a large output resistance. Under this condition, if a signal is given across the input junction, we shall get an amplified signal across the output. The transistor is said to work in the active region with this biasing arrangement.

d) Emitter-Base junction reverse biased and collector-Base junction forward biased: This is termed as the inverted condition. The transistor action ceases in this condition. This condition is not practically used.

In condition (a) and (b), transistor acts as an open or closed switch. These conditions are therefore used where a transistor is used as a switch. Condition (c) is used where the purpose of the device is signal amplification.

3-3 Transistor Circuit Arrangement

An amplifier in general should have two input terminals where we can feed the input signal and two output terminals where we can obtain output signal. Such an amplifier may therefore be represented by a four terminal network as shown in the figure.



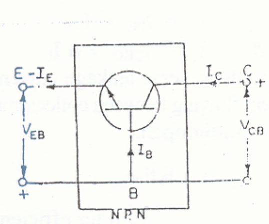
For such an amplifier, the sign convention for currents and voltages as followed in a four terminal network may be used. In this convention, a current entering into the network is taken to be positive and the current flowing out of the network is taken to be negative.

Since a transistor is a three terminal device, one of its terminals has to be common between input and output, if it is to be represented by a four terminal network.

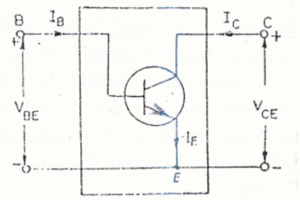
In NPN transistor circuits I_B and I_C flow into the device and taken as +ve. And I_E flows out of the device and is taken as –ve. In PNP transistor circuits, I_E is taken as +ve and I_B and I_C are taken as –ve.

a) Common Base Circuit:

In NPN transistor circuit, the base is common between the input and output. The potentials at the collector and emitter are measured with respect to base and designated as V_{CB} and V_{EB} (PNP can also taken in the same way). The polarity of the potential at the emitter or collector is marked as +ve or –ve in comparison to the common base terminal. The emitter should have a negative potential with respect to base in order that the emitter base junction becomes forward biased. So its polarity is marked as –ve. Since the collector-base junction is to be reverse biased, collector is marked as +ve with respect to base.

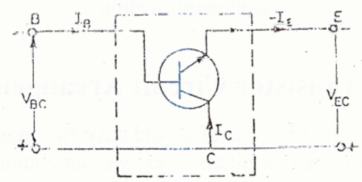


b) Common Emitter Circuit:
In this circuit, the input signal voltage is applied to the base while the output is taken out from the collector and the emitter is grounded and made common between input and output.



In common base circuits, the input current is I_E . In common emitter circuits, the input current is I_B . In both circuits, the output current is I_C . Since I_B is very small as compared to I_E , the current amplification factor which is ratio of the output current to the input current is large in common emitter circuits as compared to common base circuits.

c) Common Collector Circuit:
In this circuit, collector is made common between the input and output signals. The input signal is applied between base and collector and output signal is obtained between emitter and collector.

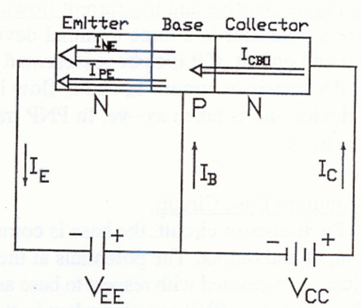


Here the input circuit comprises of a reverse biased collector-base junction. So the common collector will have the highest input impedance, which is in the range of 10^5 ohms. And the output is taken from a low impedance emitter, which makes the output impedance very low, of the order of few ohms. Since the signal is transferred from a high impedance input circuit to a low impedance output circuit, the voltage gain of this circuit is less than unity. This circuit is used for providing impedance matching between a high impedance signal source and a low impedance load and can replace an impedance matching transformer.

3-4 Current Relationships in Transistors

To understand I_B , I_C & I_E , I_{CBO} ,

Emitter current I_E consists of two parts; large *electron current* component I_{NE} , flowing from emitter towards base [for simple understanding the direction of conventional current is shown] and small *hole current* I_{PE} flowing from base to emitter, so



$$I_E = I_{PE} + I_{NE}$$

$$\& \quad I_C = I_{CBO} + \alpha I_E$$

where the reverse leakage current I_{CBO} is current flowing between collector and base with emitter open.

We define:

$$\text{Emitter efficiency, } \gamma = \frac{I_{NE}}{I_E} = \frac{I_{NE}}{I_{NE} + I_{PE}} \quad ..... (1)$$

3-4 i) Current Amplification factor (α) in CB circuit

Also called large signal gain of a common base transistor.
It is the ratio between the useful component of current reaching the output (collector) terminal to the emitter current.

$$\alpha = \frac{I_C - I_{CBO}}{I_E}$$, since I_{CBO} is very small so $\alpha = \frac{I_C}{I_E}$

or $\alpha I_E = I_C - I_{CBO}$ or $I_C = I_{CBO} + \alpha I_E$ ..... (2)

ii) Current Amplification Factor (β) in CE circuit

Also referred as the DC current amplification factor or large signal current gain of a transistor in common emitter configuration.
It is defined as:

$$\beta = \frac{I_C}{I_B}$$

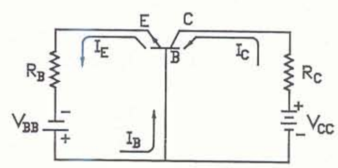
iii) Relation between α and β

We have

$$\alpha = \frac{I_C}{I_E}$$

& $$\beta = \frac{I_C}{I_B} \quad \text{..... (3)}$$

In the figure (**<u>conventional current is shown</u>**),



$$I_C + I_B = I_E \quad \text{..... (4)}$$

$$\text{or} \quad I_C / I_E + I_B / I_E = 1 \quad \text{..... (5)}$$

from equations (4) & (5) we have

$$\alpha + \frac{I_B}{I_C + I_B} = 1 \quad \text{or} \quad \alpha + \frac{1}{I_C / I_B + 1} = 1$$

$$\text{or} \quad \alpha + \frac{1}{\beta + 1} = 1 \quad \text{..... (6)}$$

or $\alpha(\beta + 1) + 1 = \beta + 1$

or $\alpha\beta + \alpha + 1 = \beta + 1$

or $\beta - \alpha\beta = \alpha$

or $\beta(1 - \alpha) = \alpha$

or $$\beta = \frac{\alpha}{1 - \alpha}$$

and from Eq. (6),

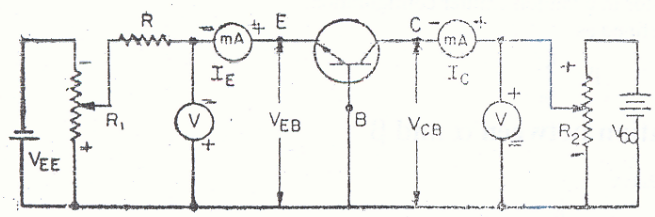
$$\alpha = 1 - \frac{1}{\beta + 1} \quad \text{or} \quad \alpha = \frac{\beta}{1 + \beta} \quad \text{..... (7)}$$

3-5 Characteristics of Transistors

It is necessary to study electrical characteristics of a transistor for working of a transistor. As DC current amplification factor α or β does not describe behaviour of a transistor completely. Static characteristic curves relate transistor currents and voltages. Dynamic input resistance relate input voltage with current for constant output voltage. Input characteristics is a plot of the input current versus input voltage for a given voltage applied at the collector. Output characteristics give a plot of output current versus output voltage for a fixed input current.

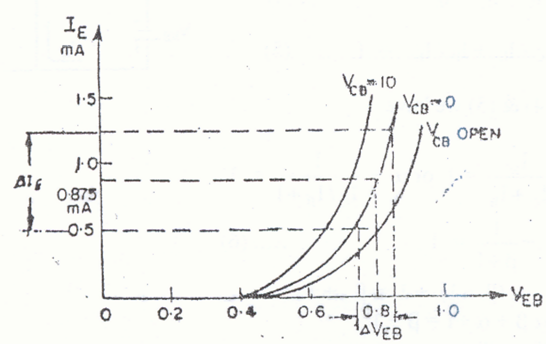
i) Common Base (CB) Characteristics

Following figure can be used for CB characteristics of a transistor.



a) Input characteristics

The following figure shows input characteristics for common base of a NPN transistor. Curves are drawn for I_E versus V_{EB} as V_{CB} is maintained constant by adjustment of R_2 .



When the collector is open circuited, the carriers complete their path through emitter-base junction and none of them can reach the collector. In this case the characteristic curve is nothing more than a forward biased junction.

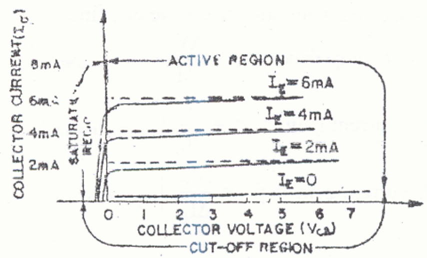
When the collector is short circuited to the base, a small current flow through the collector and I_E is increased for a given V_{EB} . The curve is shifted upwards as V_{CB} is supplied, as shown in the figure.

The *dynamic input resistance* for CB transistor is given by

$$r_i = \frac{\Delta V_{EB}}{\Delta I_E}\Big|_{V_{CB}\text{ is constant}}$$

b) Output characteristics

In the figure, for an NPN transistor, various curves are shown for I_C versus V_{CB} for constant I_E . Usually collector-base diode is reverse biased. If I_E is reduced to zero, I_C equals to I_{CBO}. The graph shows that for a given value of I_E , the I_C changes nominally with change in collector-base voltage as long as the collector-base junction is reverse biased. When this junction is forward biased, I_C shows a great dependence on this bias. A small change in collector-base forward bias causes a large change in I_C . As long as the collector junction remains reverse biased, its dynamic output resistance is very high but when it gets a forward bias, the AC resistance becomes very low. So for use as an amplifier, collector-base junction must be reverse biased. Useful region for amplification is called active region.



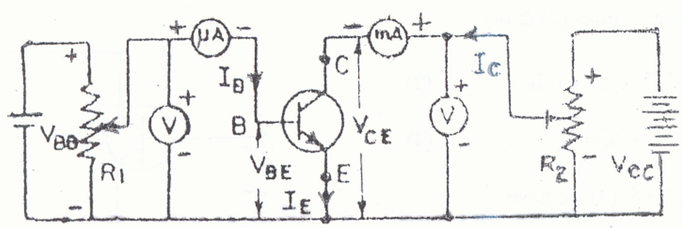
The region of characteristics where the output resistance is very low is called the saturation region.

We can determine,

$$\text{Collector AC resistance} = r_C = \frac{\Delta V_{CB}}{\Delta I_C}\Big|_{I_E = \text{constant}}$$

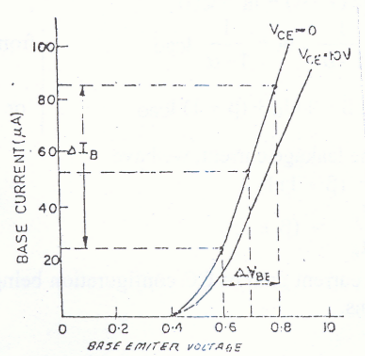
ii) Common Emitter (CE) Characteristics

For transistor circuits CE configuration is mostly used. Following figure shows a NPN transistor with circuit arrangements for the input characteristics.



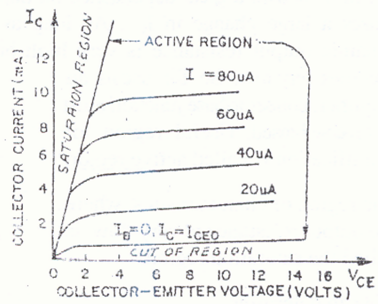
a) Input Characteristics

For input characteristics, the curves are plotted with I_B versus V_{BE} for fixed V_{CE}. With collector short circuited to emitter and base emitter junction forward biased, the input characteristic is essentially that of a forward biased junction diode. A CE circuit has very large input impedance as compared with the input impedance of the CB circuit.



b) Output Characteristics

Curves are plotted with V_{CE} versus I_C for fixed I_B . The region having a steep slope is the saturation region. This region corresponds to forward biasing of the input and output junctions. The remaining portion of the curves corresponds to active region.
In this region CB junction is reverse biased while EB junction is forward biased. The cut-off region corresponds to reverse biasing of both the input and output junctions.



From these characteristic curves we can find:

$$\text{AC collector impedance} = r_C = \frac{\Delta V_{CE}}{\Delta I_C}\bigg|_{I_B = \text{constant}}$$

$$\text{DC current gain} = \beta = \frac{I_C}{I_B}\bigg|_{V_{CE} = \text{constant}}$$

$$\text{AC current gain} = \beta' = \frac{\Delta I_C}{\Delta I_B}\bigg|_{V_{CE} = \text{constant}}$$

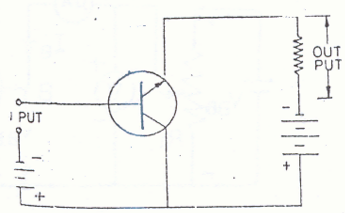
iii) Common Collector (CC) Characteristics

The circuit of CC is basically same as that of CE circuit with the exception that load resistor is in the emitter circuit rather than in the collector. The operation of the circuit in terms of the currents, which flow in the circuit, is same as for CE configuration. When the emitter is open circuited and then base current is zero, the current through the load equals to I_{CEO}.

Taking the equations (2) & (4) ,

$$I_C = I_{CBO} + \alpha I_E \quad \ldots.. (2)$$

$$I_C + I_B = I_E \quad \ldots.. (4)$$



from eqs. (2) & (4) we have

$$I_E = I_B + I_{CBO} + \alpha I_E$$

$$\text{or } I_E (1 - \alpha) = I_B + I_{CBO}$$

$$\text{or } I_E = \frac{1}{1-\alpha} \cdot I_B + \frac{1}{1-\alpha} I_{CBO}$$

$$\text{or } I_E = (\beta + 1) I_B + (\beta + 1) I_{CBO}$$

from eq. (6), or $\alpha + \frac{1}{\beta+1} = 1$

or $1 - \alpha = \frac{1}{\beta+1}$ or $\beta + 1 = \frac{1}{1-\alpha}$

neglecting the leakage current, we have

$$I_E = (\beta + 1) I_B$$

$$\text{or } \frac{I_E}{I_B} = (\beta + 1)$$

We see that current gain of CC configuration being $(\beta + 1)$, is the highest amongst the three configurations.

3-6 Load Line & Operating Point

The characteristics of a transistor are not linear as for resistance (Ohm's law). We have to operate the transistor at linear characteristics so that output in non-distorted for amplification and oscillation purposes. If input is sinusoidal we should have output has to be sinusoidal.
In order to avoid distortion we must know the operation of the transistor or conditions of working. Load line method is the best method of studying it.
Static characteristics of the transistor can help us to select an appropriate range for its operation by drawing a load line. A load line is a straight line drawn across the transistor characteristics to show how output signal current will change with input signal voltage when a specified load resistance is used. It is simply an expression of the relation of the potential difference across R_L to the collector current I_C .

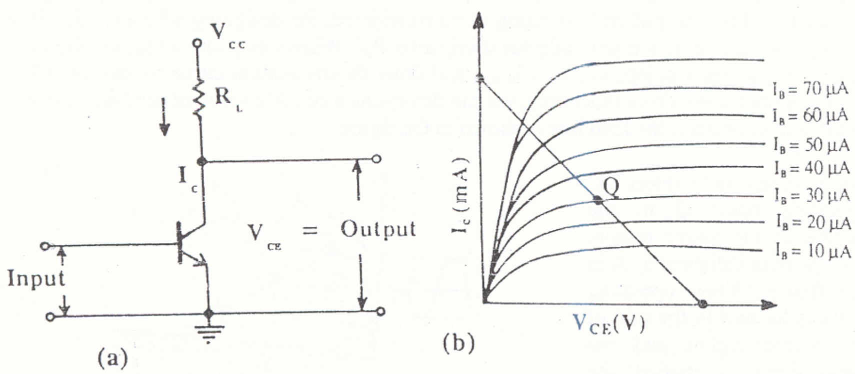


Fig. (a) shows a simple construction for common emitter transistor circuit. At a particular output "load" R_L , at which the transistor is to be operated, we have

$$V_{CC} = I_C R_L + V_{CE} \quad \text{..... (1)}$$

$$\text{or} \quad V_{CE} = -I_C R_L + V_{CC} \quad \text{..... (2)}$$

since V_{CC} and $-R_L$ are constants, so

$$x = a y + c \quad \text{..... (3)}$$

Eq. (1) represents a straight line as eq. (3) is of straight line. That straight line is known as load line. And slope on it is called slope of load line. Load line may be resistive or transformer load.

Knowing R_L if V_{CE} is to be maximum

$V_{CE} = V_{CC}$, then $I_C = 0$

Let $V_{CC} = 6$ volts, $I_C = 0$

Take point A on the graph

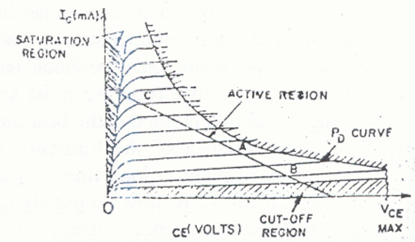
Next $I_C \max = \dfrac{V_{CC}}{R_L}$, when $V_{CE} = 0$

This will be a point B.

The line AB is called DC load line, since its slope depends upon "load" R_L .

From it we can select the 'optimum quiescent operating point', Q, to allow the maximum positive and negative swing. Generally the 'Q' point is selected about half-way on the load line. So these characteristics can be used to determine power developed across R_L .

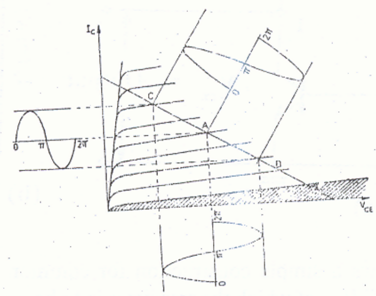
Operating Point



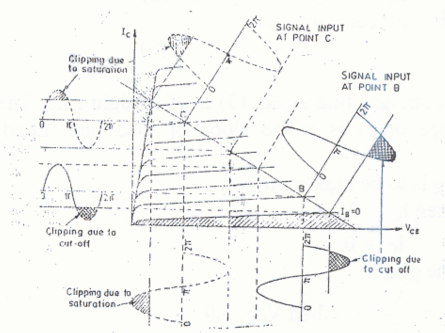
Amplifier circuits to imply an input signal properly, its operating point has to be selected carefully. The transistor has to be operated in the active region by giving a forward bias to emitter base junction and reverse bias to collector-base junction. The amplifier will give an output signal that is proportional to the input signal, when the transistor is properly biased.

Such an amplifier that gives the signal output that is exact reproduction of the input signal is termed as a linear amplifier. The rating to be considered, for designing a biasing circuit, are $I_{C\ max}$, $V_{CE\ max}$ and maximum collector dissipation P_D . When designing a biasing circuit, the first step is to mark points $V_{CE\ max}$, $I_{C\ max}$ and draw the dissipation curve for the rated P_D as shown in the figure. From this curve, we can determine a suitable value of load resistor. For a suitable load resistor, the load line is shown in the figure.

The next step is to select DC operating point Q in the middle of the above region. This point is indicated as A in the figure. When operating point is located in the mid of the active region and the input signal is applied, the excursions in the collector voltage are shown in the figure.



Large excursions in collector voltage and current can take place as the point Q is in the mid of active region. The positive and negative half cycles of the input signal are equally amplified and output is undistorted.



If the operating point is situated near cut-off, negative half cycles of the signal output are clipped. If the operating point is located near saturation, positive half cycles of the signal output are distorted. It is shown in the figure below.

3-7 Hybrid Parameters

A transistor equivalent circuit that is most commonly used by transistor manufacturers to specify the transistor characteristics is with the use of hybrid-parameters (or h-parameters). These parameters are easy to measure and are a mixture of constants having different units.

The behaviour of any four terminal network may be described by the following network equation.

$$v_1 = h_{11}\, i_1 + h_{12}\, v_2 \qquad \text{..... (1)}$$

$$i_2 = h_{21}\, i_1 + h_{22}\, v_2 \qquad \text{..... (2)}$$

where v_1, v_2 , i_1 and i_2 are parameters of the network as shown.

The parameters h_{11} , h_{12} , h_{21} and h_{22} are the four variables that describe the behaviour of the network. The values of these parameters can be found out from eqs. (1) & (2).
Assume that we short circuit the output terminals, then v_2 becomes zero. From eqs. (1) & (2) we have

$$v_1 = h_{11}\, i_1 \qquad \text{..... (3)}$$

$$i_2 = h_{21}\, i_1 \qquad \text{..... (4)}$$

from eqs. (3) & (4) we get

$$h_{11} = \frac{v_1}{i_1} \quad \text{and} \quad h_{21} = \frac{i_2}{i_1}$$

now assume that we open circuit the input point so that the input current i_1 becomes zero. Then from eqs. (1) & (2) we have

$$v_1 = h_{12}\, v_2 \qquad \text{..... (5)}$$

$$i_2 = h_{22}\, v_2 \qquad \text{..... (6)}$$

from eqs. (5) & (6) we have

$$h_{12} = \frac{v_1}{v_2}$$

and $$h_{22} = \frac{i_2}{v_2}$$

the values of h-parameters as obtained are written below,

$$h_{11} = \frac{v_1}{i_1} \Big|_{v_2=0} = \text{Input impedance with output terminals shorted}$$

$$h_{21} = \frac{i_2}{i_1} \Big|_{v_2=0} = \text{Forward current gain with output terminals shorted}$$

$$h_{12} = \frac{v_1}{v_2} \Big|_{i_1=0} = \text{Reverse voltage transfer with input terminals open circuited}$$

$$h_{22} = \frac{i_2}{v_2} \Big|_{i_1=0} = \text{Output admittance with input terminals short circuited}$$

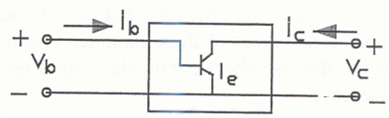
A transistor is a three terminal device but since one of its terminal is kept common between input and output, it may be represented by h-parameters described for a four terminal transistor as shown in the figure. Its h-parameters may be written as:

Input impedance: $h_{ie} = \frac{v_b}{i_b} \Big|_{v_c=0}$

Forward current gain: $h_{fe} = \frac{i_c}{i_b} \Big|_{v_c=0}$

Reverse voltage feedback: $h_{re} = \frac{v_b}{v_c} \Big|_{i_b=0}$

Output admittance: $h_{oe} = \frac{i_c}{v_c} \Big|_{i_b=0}$



The second foot letter 'e' used in these h-parameters indicates that these parameters are for common-emitter configuration. Similar parameters for a common-base configuration may also be obtained.

Chapter-4

Amplifiers

4-1 Definition & Types

An amplifier is a device that increases the amplitude or magnitude of the given signal.

An amplifier has four important parameters namely: voltage gain, band width, input impedance and output impedance. These parameters are fixed for a given amplifier.

There are three types of amplifiers.

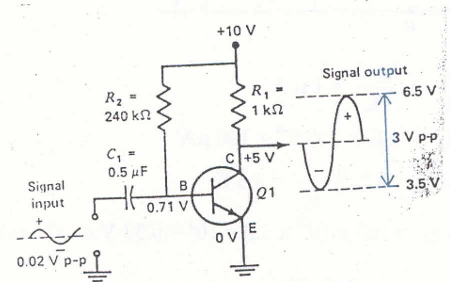
a) Voltage amplifier—to increase the voltage level of an input signal.
b) Current amplifier—to increase the input current signal.
c) Power amplifier—to increase the power level of the input signal.

An ideal amplifier reproduces the original wave shape of an input signal. Practically distortions occur, they can be reduced but can never be completely removed.

[**Band width**: The difference between the upper and lower frequency limits, i.e., the range, over which a particular characteristic of an electronic device lies within specified limits.]

4-2 The transistor as an Amplifier

Consider common-emitter amplifier circuit with bias level halfway between cutoff and saturation as shown in the figure. The DC biasing levels are set by the feedback resistor R_2 . The NPN transistor is biased so that the collector-to-emitter voltage V_C is half of the supply voltage. For the supply voltage of 10 V, the collector voltage is set therefore at +5 V, which is one half the total voltage. the 0.7 V at the base is partially turning on the transistor. The transistor acts as an amplifier when in this partially turned on condition. It is the amount of DC forward bias that determines the operating level of the transistor.



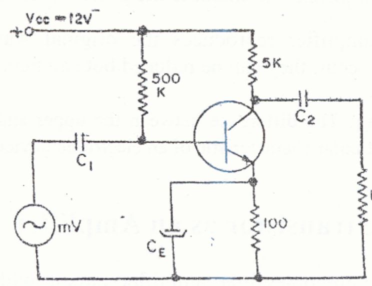
4-3 Amplifier circuit analysis using h-parameters

Hybrid (h-) parameters are conveniently used for estimating voltage gains of small signal amplifiers. We take a ratio of small change in I_C to the small change in I_B to determine β. The following is the step-by-step procedure.

i) Mark collector, base and emitter points of the transistor by drawing a circuit diagram of the transistor.
ii) Remove the transistor and replace it with its hybrid equivalent circuit as given in fig.
iii) Replace all capacitors by their reactance.
iv) Replace DC supply by its internal resistance.
v) Calculate I_B and then I_C .
vi) Find output voltage and the its gain.

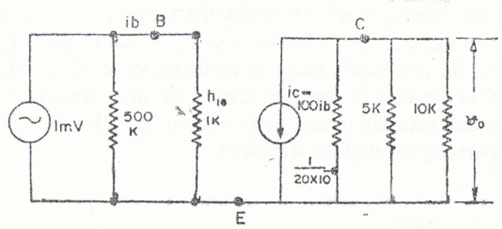
EXAMPLE:

Determine the output voltage and voltage gain of the amplifier shown in the figure. Assume the transistor parameters to be h_{ie} = 1 K, h_{fe} = 100, h_{re} = negligible, $h_{oe} = 20 \times 10^{-6}$ S. Reactances of C_1 , C_2 , C_E negligible at operating frequency.



Solution:

Draw the hybrid equivalent circuit.



$$i_b = \frac{v_i}{h_{ie}} = \frac{1\text{mV}}{1\text{K}} = 1\ \mu\text{A}$$

$$i_e = h_{fe}\ i_b = 100 \times 1 \times 10^{-6} = 100\ \mu\text{A}$$

AC load $r = 5\text{ K} \parallel 10\text{ K} \parallel \frac{1}{h_{oe}} = 3.3\text{ K}$

Therefore $v_o = i_e,\ r_L = 100 \times 10^{-6} \times 3.3 \times 10^3 = 0.33$ V or 330 mV

Voltage gain $= A_v = \frac{v_o}{v_i} = \frac{330\text{mV}}{1\text{mV}} = 330$ $V_o = 330$ mV ,

or $A_v = 330$

4-4 Feedback Amplifiers

A feedback amplifier is one in which the amplifier input is in part derived from an external signal source and in part from the amplifier output.

If the net effect of the voltage taken from the amplifier output is to increase the effective input signal, the feedback is called positive or regenerative. If the resultant input is reduced by the feedback, the feedback is called negative or degenerative.

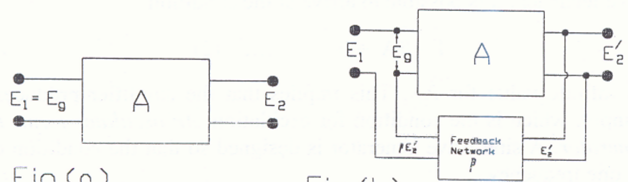


Fig.(a) Fig.(b)

Basic Principle:

Fig. (a) shows an amplifier without any feedback connection. An input signal voltage E_1 directly appears between grid and cathode so that $E_g = E_1$. The output voltage is E_2 , so voltage gain A of the amplifier is :

$$A = \frac{E_2}{E_1} \quad \text{..... (1)}$$

As shown in the fig. (b), a fraction β of the output voltage is fed through a feedback network. Due to this feedback, the input voltage between grid and cathode as well as the output voltage is modified.

Now the overall gain A_f of the amplifier with feedback will be:

$$A_f = \frac{E_2'}{E_1} = \frac{A}{1-\beta A} \quad \text{..... (2)}$$

Where E_2' = output voltage, βA = closed loop gain

Both A and β are vector quantities, having magnitude and phase. Every common emitter amplifier stage introduces a phase shift of 180^0 . Usually the phase of β is arranged to have a value of zero or 180^0 .

In eq. (2) if βA is negative, the overall gain A_f becomes smaller than A. The feedback is then referred to as Negative feedback. This happens when β and A have opposite signs, so that the product βA becomes negative. If βA is positive, the overall gain A_f becomes larger than A. The feedback is called positive feedback. This happens when β and A have same phase, so that the product βA becomes positive and the denominator (1 - βA) becomes less than unity. So the gain is increased. If βA is positive and equals unity, the denominator in the equation becomes zero and the gain A_f becomes infinite. Under this condition, the amplifier output will be available even after the input has been removed. This happens because the infinite gain of the system enables it to provide its own input signal through the feedback path. Such a system is termed as an *Oscillator*.

4-5 Positive Feedback

One of the most useful test instruments in experimental electronics is the signal generator Positive feedback is the basic factor common to signal generators. In the last section, we see that the gain A_f of the amplifier with feedback is:

$$A_f = \frac{A}{1-\beta A} \quad \ldots.. \quad (1)$$

In case of positive feedback, it is possible to arrive at the condition

$$1 - \beta A = 0 \quad \ldots.. \quad (2)$$

which gives an infinite value for A_f . This implies that the amplifier produces an output signal with no input, which is the condition for oscillation. *An oscillator forms the heart of every signal generator*. A sine-wave generator is designed so that the condition of eq. (2) is satisfied at only one frequency.

4-6 Negative Feedback

In the equation

$$A_f = \frac{A}{1-\beta A} \quad \ldots.. \quad (1)$$

When β or A is negative, the denominator will be greater than one, and we will get negative feedback in the amplifier.

Advantages

The three types of amplifiers [see section 4-1] may be made to exhibit the properties of any other type by proper application of negative feedback. Also their types may be improved by proper use of negative feedback. As an example, a high input resistance of a voltage amplifier can be made higher, and its low output resistance can be lowered. Also total gain of the amplifier with feedback can be stabilized against variations of the *h* parameters of the transistors. And there is significant improvement in the frequency response and in the linearity of operation of the feedback amplifier compared with that of the amplifier without feedback. Special precautions must be taken, as sometimes a negative feedback amplifier may become unstable and break into oscillations.

Disadvantages

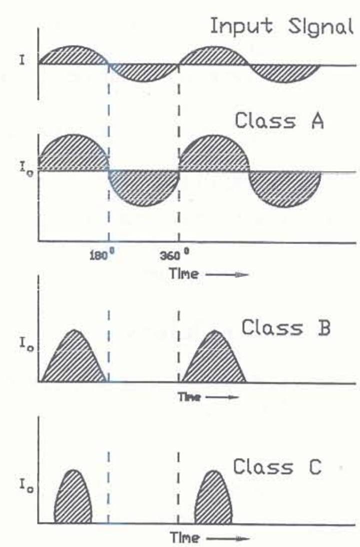
The negative feedback reduces the overall gain of the amplifier. It is not the big price to pay as compared the benefits derived. Usually, for example operational amplifier, the gain is much more than needed. Second disadvantage is the problem of oscillation into the system. If the loop transmission phase shift and attenuation characteristics are not properly controlled, the system may become unstable, as the loop gain is dependent upon frequency.

4-7 Class of Operation for Amplifiers

The amplifier class of operation is defined by the percentage of the input signal that is able to produce output current.

Over here it is seen whether any part of the input cycle cut off in the output. It depends upon DC bias compared with the cutoff value of the voltage, and secondly peak AC signal compared with the DC bias.

The class of operation used for an amplifier depends on the requirements for minimum distortion, maximum ac power output, and efficiency. The figure illustrates the input and output waveforms for class A, B, and C amplifiers. It is in terms of output collector current I_C for the transistor.



Class A Operation

Here the output current I_C flows for the full cycle of 360^0 of input signal. The ac signal swings I_O around the middle value. It is used for *audio amplifiers*, in a single stage for minimum distortion. Most small signal amplifiers operate class A.

Class B Operation

Here the output current I_C flows for 180^0 or half of input signal. The dc bias is near the cutoff value and I_C is close to zero. This class of operation requires more dc bias and more ac signal as compared to class A. This operation leads to half wave rectification with a single stage. Connected in pair, two stages can provide opposite half cycles of the signal. Such a circuit is called a *push-pull amplifier*. This circuit arrangement is usually used for *audio power output to a loudspeaker.*

Class C Operation

Here the output current I_C flows for 120^0 or less than one-half of input cycle. It gives the highest efficiency, and is used for *tuned RF power amplifiers*. The LC circuit can provide a full sine-wave cycle of output to each pulse of I_C .

Few Definitions:

Bias voltage: A voltage applied to an electronic device to produce the desired characteristic.

Distortion: The degree by which the output signal wave shape differs from the input signal wave shape.

Efficiency: It is the ratio of the ac power output to the dc power dissipated at the output.

Chapter 5

Oscillators

5-1 Definition & Principle

An oscillator is a device that generates alternating signals of a constant frequency when DC power is given to it.

Oscillators are required when alternating signals are required over a wide range of frequencies, that is, from a few Hertz to more than 10^7 Hertz. Oscillators play an important role in test and measuring equipments, radio, TV transmitters and receivers, for dielectric and induction heating, and communication services. An oscillator, in effect, converts power delivered by the dc supply voltages into ac power having the desired characteristics.

Principle of Oscillator

In each oscillator, oscillations take place in some circuit that contains an induction and a capacitance. In order to maintain the oscillations energy is supplied to this circuit by some method, so that it exactly balances the losses and hence the amplitude of oscillations is kept constant.

5-2 R-C Oscillators

Oscillators are named after the type of feedback network used. Accordingly there are two types of oscillators.

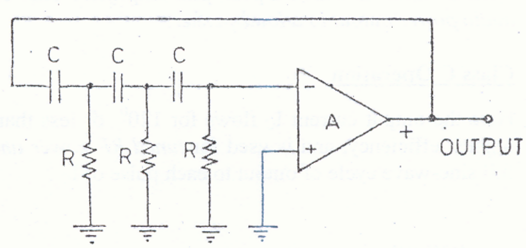
i) R-C oscillators, ii) L-C oscillators

In R-C Oscillators, Resistor and Capacitor elements are employed as feedback network. Two of them we will mention.

a) Phase shift Oscillator

In phase shift oscillator, we use a single stage amplifier. This amplifier has a phase shift of 180^0 between input and out put amplification. To produce positive feedback, we use such network that additional phase shift of 180^0 is introduced and overall phase shift becomes zero.

We use three R-C combinations to provide 60^0 by each phase shift, to make total equal to 180^0, as shown in the figure. The negative input signal causes the output positive. At a particular frequency, the total phase shift will be zero. If at this frequency, the value of $A\beta$ is equal to or greater than unity, then oscillations will occur at this frequency.



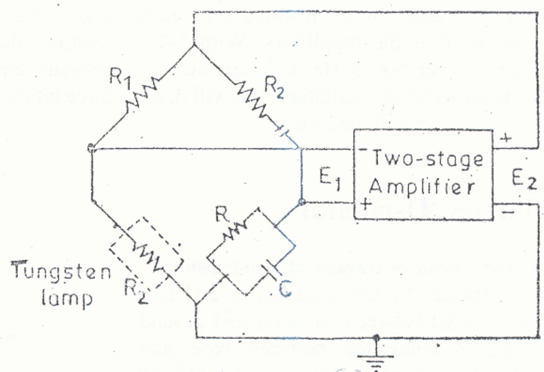
Mathematically the frequency of oscillations is given by

$$f = \frac{1}{2\pi RC\sqrt{6}} \quad \text{and} \quad \text{feedback factor, } \beta = \frac{1}{29}$$

this means voltage gain A must be made greater than 29 so that $A\beta$ becomes greater than unity.

b) Wein Bridge Oscillator

In Wein bridge oscillator, there is simultaneous change of either R or C, for bringing a change in the oscillator frequency. Here the gain required is very small as compared to phase shift oscillator and can be met easily. The circuit comprises of a two-stage amplifier, the output of which is fed as input to a Wein bridge as shown in the figure. The output of the bridge is given as input to the amplifier.



In the input connections of the amplifier, the minus (inverting) point will serve as base and plus (non-inverting) will be like emitter. The signal appearing at inverting terminal has the same phase as the output because it is obtained from a resistive network. As there is phase shift of 180^0 at this terminal, it will give a negative feedback to the amplifier.

When the circuit will be on, the tungsten lamp forming the bridge arm offers a low resistance and there is no negative feedback and $A\beta > 1$.

Oscillations build up due to positive feedback at a frequency at which the bridge is balanced. It is given as,

$$f = \frac{1}{2\pi CR}$$

As oscillations build up, the output increases and the current flowing through the tungsten lamp heats it up. Resistance of the lamp increases. This increases the negative feedback. As a result the amplifier gain is reduced. At a particular point, the value of tungsten lamp resistance R, the product $A\beta = 1$.

The gain A between non-inverting input and output will be

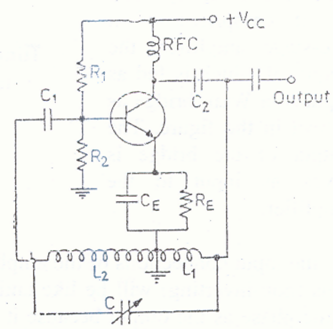
$$A = \frac{R_1}{R_2} + 1$$

frequency of the oscillator is inversely proportional to the resistor or capacitor and can be varied by adjustment of these components. Wein bridge oscillator is used as a standard oscillator for all low frequencies in the range of 5 Hz to about 1 M Hz. Its common application is as audio oscillator.

5-3 L-C Oscillators

For low frequency applications, L-C oscillators are used. As in R-C oscillators, above 1 MHz the value of R and C in the lead-lag network becomes extremely small and begins a problem of phase shift in the amplifiers. With L-C oscillators, the range of oscillations can be extended to over 500 MHz. L-C circuits form resonant circuits and are connected in the feedback networks in oscillators. We will discuss three types of L-C oscillator circuits. Three of them we will mention.

a) Hartley Oscillator



The Hartley oscillator consists of auto-transformer coupling formed by the windings L_1 and L_2, L_1 is connected between collector and ground while L_2 is connected between base and ground. The resonant circuit is formed by connecting L_1 and L_2 in series.

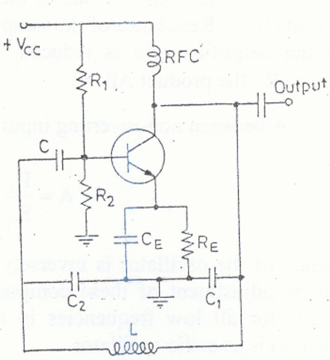
The collector supply is applied through a radio frequency choke (RFC) which allows an easy flow of DC current but offers high reactance for oscillatory signal. The oscillatory signal develops across RFC and is coupled through coupling capacitor C_2 to L_1.

As a result, the circuit is set into oscillations and the voltage developing across L_2 is given as feedback to base. Resonant frequency of the oscillator is given by

$$f = \frac{1}{2\pi\sqrt{LC}}\,, \qquad \text{where L is the resultant of the coils } L_1 \text{ and } L_2$$

In transistor receivers, Hartley oscillators are commonly used.

b) Colpitts Oscillator



Here capacitive tapping is used instead of inductive tapping. Its circuit is nearly same as that of Hartley oscillator, only the coils L_1 and L_2 are replaced by capacitors C_1 and C_2 and a single coil L forms the resonant circuit. The ratio C_1/C_2 decides the magnitude of feedback between input and output. Resonant frequency of the oscillator is given by

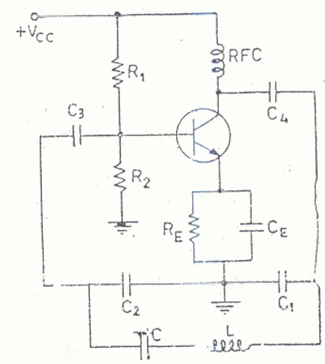
$$f = \frac{1}{2\pi\sqrt{LC}}\,,$$

where C is the series resultant of C_1 and C_2

In commercial signal generators, above 1 MHz frequency, Colpitts oscillator is used.

c) Clapp Oscillator

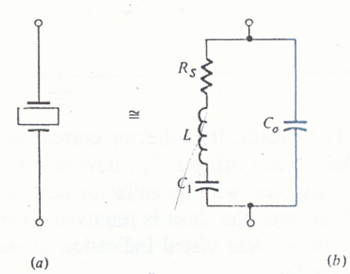
Its circuit is similar to that of Colpitt oscillator, only a capacitor C is added in series with the coil L. C and L form a series resonant circuit. The frequencies higher than resonant frequency, the circuit behaves as inductive reactance. This inductive reactance forms a parallel resonant circuit with the series combination of C_1 and C_2 and determines the oscillator frequency. It gives a better frequency stability than Colpitt oscillator.



5-4 Crystal Oscillators

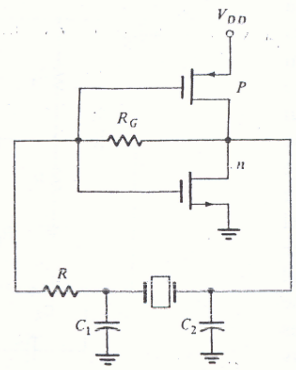
Crystal oscillator is a vèry important component of the digital signal processing system. Crystals are often used for very good frequency stability. They serve as sole controlling element for the frequency of oscillation. The accuracy of the total timing system is entirely dependent on the accuracy of the oscillator. Some crystals found in nature are seen to exhibit the piezoelectric effect. When we apply an alternating voltage across them, these crystals vibrate and the frequency of vibration is found to be same as the frequency of the alternating voltage. If mechanical vibrations are forced in these crystals by application of some mechanical energy, an alternating voltage is generated in these crystals. Examples are Rochele salt, tourmaline and quartz crystals.

Figures below show the symbol and the circuit model of a vibrating piezoelectric crystal. The Q of a crystal can be as high as several hundred thousand. Typical values for a 10 MHz quartz crystal are $Q = 1.5 \times 10^5$, $C_o / C_1 = 300$, $L = 12$ mH, $R_s = 5$ ohms & $C = 10^{-11}$ F. The analysis of the circuit is similar to that of LC oscillator.



[**Piezoelectric effect**: The generation of a small potential difference across certain materials when they are subjected to a stress.]

A **CMOS oscillator** circuit is shown below. It is often used in timing circuits. CMOS amplifier provides the gain and a phase reversal at the crystal frequency. The following is the circuit diagram of a Colpitts crystal oscillator using a CMOS amplifier.

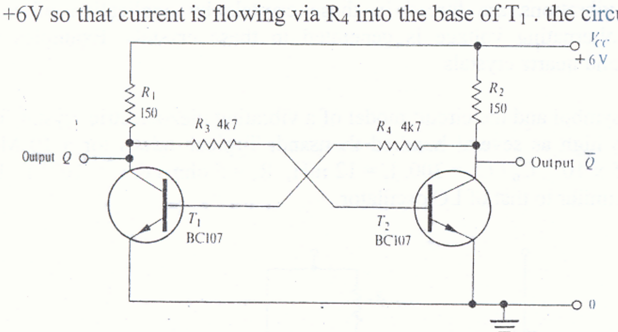


5-5 Bistable Multivibrator

Multivibrators are oscillators that produce voltage pulses and extended voltage waveforms of almost square shape usually occurring periodically.

The bistable multivibrator has two stable states. It is also called *flip-flop* circuit.

Consider two-transistor circuit as shown in the figure. Actually it is two transistor switches connected to one another. Let T_1 is turned on first, when the supply is on. When saturated, its collector will be within 0.3 V. So no current can flow through R_3 into the base of T_2 , because it takes 0.6 V to conduct in the silicon junction. And T_2 will remain off and its collector is up at +6V so that current is flowing via R_4 into the base of T_1 . the circuit is in a stable state.

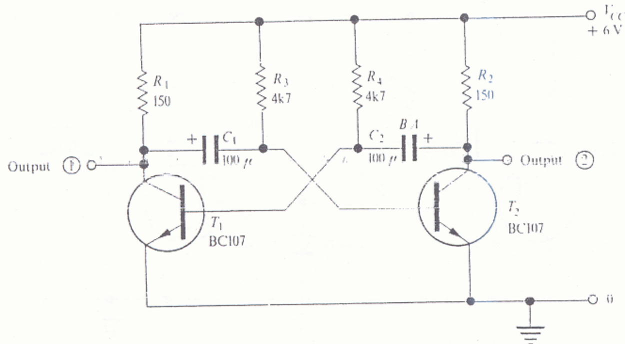


Now short the base of T_1 to earth. Its collector current will fall to zero and its collector voltage rise to +6V. T_1 has turned off, but T_2 , now receives a base current flowing in R_3 , which switches it on. T_2 saturates, with its collector near to zero volts, thus preventing any current flowing into T_1 base even the short is removed. Once more the circuit is in a stable state, but this time T_2 is on. A clear visual indication of state is obtained if R_1 and R_2 are replaced with (6V, 0.04A) bulbs.

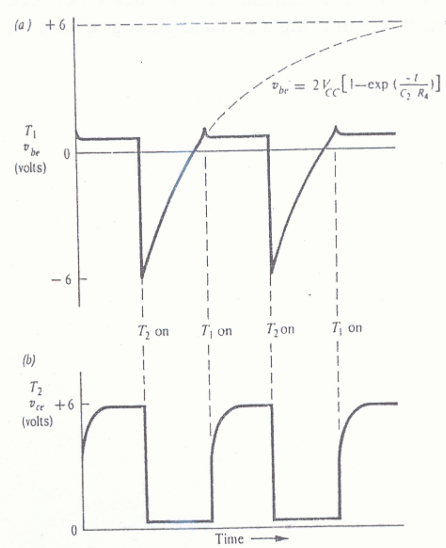
The bistable multivibrator acts as an electrical memory, remembering which transistor was last triggered off. It is a basic building brick in digital circuits, being employed in counters and memories.

5-6 Astable Multivibrator

The circuit of astable multivibrator is nearly same as that of bistable multivibrator, only capacitor-coupling is used instead of resistor-coupling between the transistors. Let the circuit contains 6V, 0.04A bulbs as the 150 Ω collector loads. The transistors switch alternately on and off with a frequency determined by the time constants C_1 R_3 and C_2 R_4. Bulbs of 6V, 0.04A, can be used for R_1 and R_2.



Assume that T_1 has just switched off, its collector is raising upto +6V, and T_2 has just turned on. The plate A of capacitor C_2 is connected to T_1 collector and has at +6V, while plate B is connected to T_1 base has at +0.6V because T_1 was conducting. C_2 therefore has a 5.4V across its plates. It considerable charge which the capacitor is to release. Now at the instant when T_2 switched on, plate A went down to earth with T_2 collector and, momentarily, the 5.4V potential difference between plates A and B was maintained. Plate B therefore was pulled down to –5.4 V, turning off T_1 by taking its base negative. C_2 then begins to charge in the opposite direction via R_4 , which is connected to +6V. Now the base of T_1 is aiming at +6V with a time constant R_4 C_2 . But it never reaches there, as soon as it reaches 0.6V T_1 turns on, starting the whole processes again, C_1 taking the base of T_2 to –5.4V and charging via R_3.

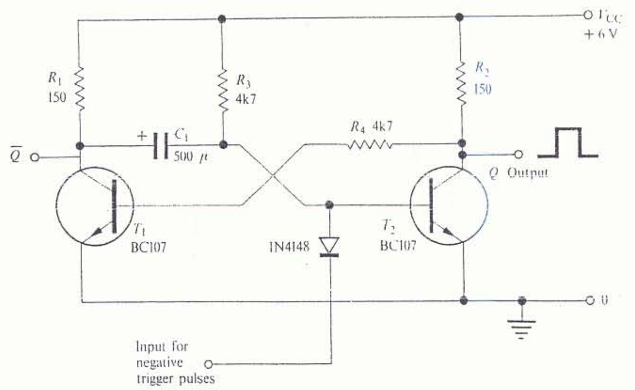


The figure (a),shows a plot of T_1 base voltage during the cycle. Here the interruption of the exponential charge of C_2 via R_4 can be seen. A slight overshoot is seen as a positive pulse is driven into T_1 base by T_2 switching off.

In figure (b), T_2 collector voltage is plotted against time.

5-7 Monostable Multivibrator

The circuit of monostable multivibrator is a cross between the bistable and astable multivibrators. It has one D.C. coupling and one capacitive coupling. The result is that the monostable has only one stable state, with T_2 on and T_1 off.



By shorting the base of T_2 to earth, triggering of monostable into its second state is readily achieved. Bulbs of 6V, 0.04A, can be used for R_1 and R_2.

Monostable multivibrators are used in the production of pulses of a desired width, and the provision of an adjustable time delay between successive events. As a practical example, time between firing a gun and photographing the bullet in flight.

Chapter 6

Digital Electronics

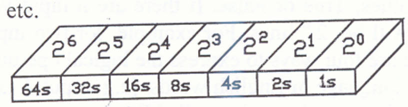
6-1 Binary Logic Gates

Digital electronic devices use a special number system called *binary.* Digital computers and microprocessor-based systems use another special number system called *hexadecimal.* [This number system uses the 16 symbols 0,1,2,3,4,5,6,7,8,9,A,B,C,D,E and F and is referred as the base 16 system.] We should know how to convert numbers from one system to another.
A number system is a code that uses symbols to refer to a number of items. The decimal number system uses the symbols 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9. This decimal number system contains 10 symbols and is called the base 10 system.

Looking for the idea of the **place value in the decimal system**. Consider the decimal number 732. The digit 7 represents 700 because of its placement three positions left of the decimal pint. The digit 3 represents 30 because of its placement two positions left of the decimal point. The digit 2 represents two units because of its placement one position left of the decimal point. It is shown below.

	Hundreds		Tens		Units
732 =	700	+	30	+	2

The idea of place **value in binary system** is also used. The following figure show the value of the places left of the binary point in decimal and in powers of 2. For example, we see that 8s place is the same as the 2^3 position, etc.



For **Binary to Decimal conversion**, consider the binary number 11001. Writing it as following.

Binary	1	1	0	0	1				
Decimal	16	+ 8		+	1	=	25		

We see that binary 11001 equals the decimal number 25.

For **Decimal to Binary conversion**, consider decimal number 19. One of the procedure is as following.

Decimal number

19 ÷ 2 = 9	with a remainder of	1	1s
9 ÷ 2 = 4	with a remainder of	1	2s
4 ÷ 2 = 2	with a remainder of	0	4s
2 ÷ 2 = 1	with a remainder of	0	8s
1 ÷ 2 = 0	with a remainder of	1	16s

binary number

Please note that we stop dividing by 2 when the quotient becomes 0. So decimal number 19 is equal to 10011.

The term **logic** is usually used to refer to a decision making process. A logic gate, then, is a circuit that can decide to say yes or no at the output based upon the inputs. Logic deals with variables that are either True (T) or False (F). No other values are allowed. There may be other meanings associated with the word logic, but only the values True and False are considered. To make it understand more in details, considering one example. True means 'sunlight at daytime' and False means 'moon light at nighttime'. However within the context of logic, only the values of True and False are considered. The actual meaning associated with these variables is outside the context of logic. In electronics a logical circuit deals only with the voltages corresponding to True or False, not the meaning associated with these terms.

Boolean algebra first studied by George Boole, is the algebra of a two state variable. In Boolean algebra, the variables can be only 0 or 1. The basic operations in the algebra are addition, multiplication and negation.

Logic gates are electronic circuits designed to perform logical functions based on *Boolean algebra*. Normally these circuits operate between two discrete voltage levels, i. e., high and low levels, and described as binary logic. Logic gates are building blocks for even the most complex computers. The logic gates can be constructed by using simple switches, relays, diodes, transistors, or IC's.

The basic **logical operations** are AND, OR, and NOT. The meaning of these logical operations is demonstrated by Truth Tables. These are the tables where the resultant output is indicated for every possible combination of input variables. As each logical variable can take only two values, True or False. If there are n input variables, then the number of lines in a truth table will be 2^n lines. For example, for two input variables, the truth table has $2^2 = 4$ lines. There are four ways to express the logical operations.

a) In the language of English words. [e.g. Input A is ANDed with input B to get output X]
b) In mathematical notation called Boolean expression. [e.g. $A \bullet B = X$]
c) In a logical symbol. [see fig. below]
d) In a Truth Table. [see fig. below]

6-2 Three Basic Gates

Three gates corresponding to three basic logical functions are OR, AND & NOT gates.

a) OR Gate

OR gate is a circuit with two or more inputs and one output whose output is high if any one or more of the inputs are high. The Boolean expression, logic symbol and truth table for two inputs are given below.

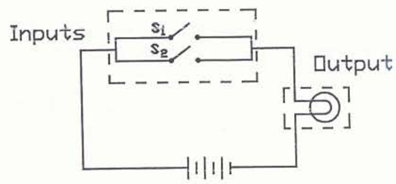
$$A + B = C$$

Input		Output
A	B	C
0	0	0
0	1	1
1	0	1
1	1	1

The standard packages usually contain four 2-input gates, three 3-input gates, or two 4-input gates. For example, 4-input OR gate will have a High output if any one input or more is High.

Practical Circuits

Switch OR gate:



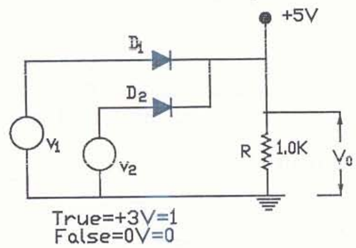
Diode OR gate:

If $v_1 = v_2 = 0V$, then $v_o = 0V$

Now let $v_1 = +3V$, $v_2 = 0V$, then $v_o = +3V$

Let $v_1 = 0V$, $v_2 = +3V$, then $v_o = +3V$

When both $v_1 = v_2 = 3V$, then $v_o = 3V$

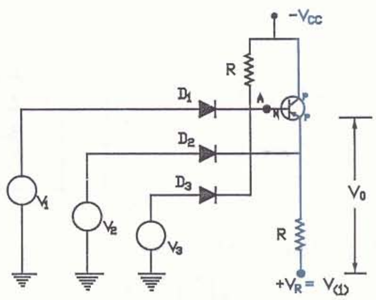


DTL (diode transistor logic OR Gate) :

The logic levels are:

$V_{(0)} = 0V = 0$

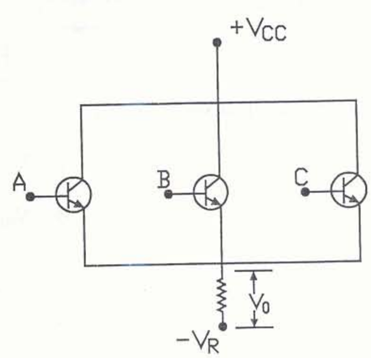
$V_{(1)} = +5V = 1$



TTL (Transistor Transistor Logic):

$V_{(0)} = 0V = 0$

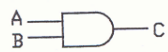
$V_{(1)} = +5V = 1$



b) AND Gate

AND gate is a circuit with two or more inputs and one output in which the output signal is high if and only if all the inputs are high simultaneously. That is, AND gate has output 1 when both inputs are 1. It is *all-or-nothing* gate because an output occurs only when all its inputs are present. The Boolean expression, logic symbol and truth table for two inputs are given below.

$$A \cdot B. = C$$

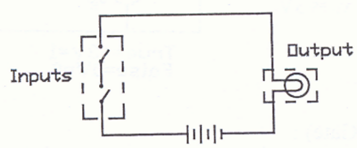


Input		Output
A	B	C
0	0	0
0	1	0
1	0	0
1	1	1

AND gates are available with 3 or 4 or more inputs. For example, 8-input AND gate will have a High output only if all inputs are High.

Practical Circuits

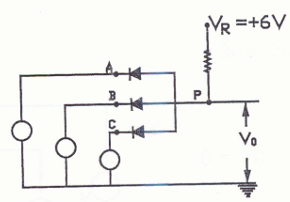
Switch AND gate:



Diode AND gate:

$1 = V_{(1)} = +5V$

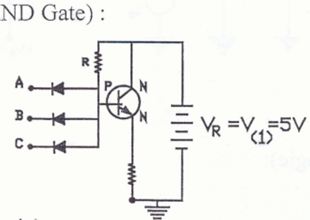
$0 = V_{(0)} = 0V$



DTL (diode transistor logic AND Gate) :

$1 = V_{(1)} = +3V$

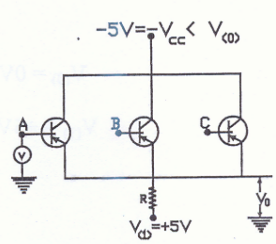
$0 = V_{(0)} = 0V$



TTL (Transistor Transistor Logic):

$1 = V_{(1)} = +3V$

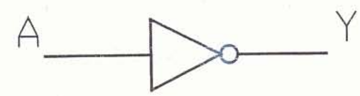
$0 = V_{(0)} = 0V$



c) NOT Gate

NOT gate is a circuit with one input whose output is high if the input is low and vice versa. It is also called an *inverter* because it inverts the output. In this gate the output is always complement of the input, i.e., if input is 1 or high then output is 0 or low and vice versa. The Boolean expression, logic symbol and truth table are given below.

$Y = \bar{A}$



Three ways for writing Truth Table

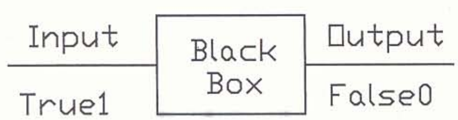
Input	Output
A	$\bar{A}$
H	L
L	H

Input	Output
A	$\bar{A}$
T	F
F	T

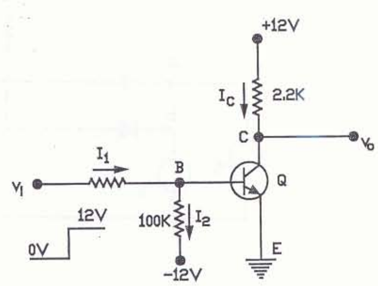
Input	Output
A	C
1	0
0	1

Practical Circuits

Black Box:



Transistor Inverter:



The term inverted means that, when the base voltage goes positive, the collector voltage drops from +V to near 0; when the base goes negative, the collector goes positive.

6-3 NAND Gate

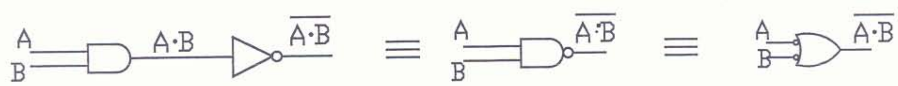
The three most fundamental logic gates are; OR, AND, and NOT gates. NAND gate is the combination of AND and NOT gate. It is NOT AND, or inverted AND function. It is a circuit with two or more inputs and one output, whose output is high if any one or more of the inputs is low, and low if all the inputs are high.
NAND gates are commonly employed in industrial practice and extensively used in all digital equipments. The unique output from the NAND gate is a LOW only when all inputs are HIGH. The Truth Table shows that only line 4 generates a 0 while all other outputs are 1. The Boolean expression, logic symbol and truth table are given below.

NAND = NAND is NOT AND

$\overline{A \cdot B} = C$

Input A	Input B	Output
0	0	1
0	1	1
1	0	1
1	1	0

The following figure shows a separate AND gate and inverter being used to produce the NAND logic function.



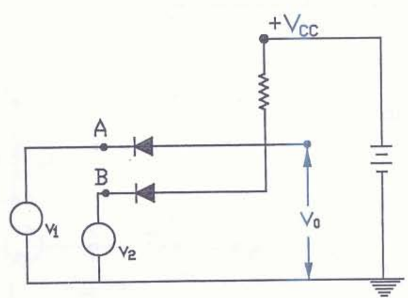
Practical Circuit

Diode NAND gate:

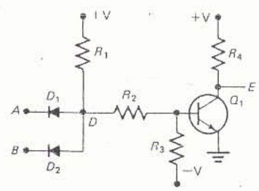
Logic level:

1 = +V

0 = 0V



DTL (diode transistor logic NAND Gate) :



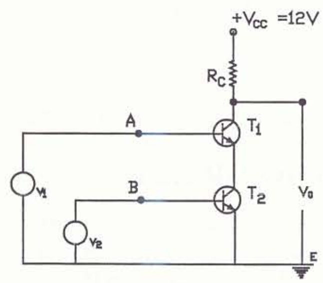
The above figure shows a transistor Q_1 with CE connection, and its collector output is inverted. Such a circuit having an inverting transistor is called a NAND gate.
In figure (a), diodes D_1 and D_2 with resistor R_1 act like the AND gate. When inputs A and B are made many volts positive, point D also rises to a positive voltage sufficient to turn transistor Q_1 on. But if either A or B is near 0 volts, -V applied through resistor R_3 ensures that Q_1 turns fully off.

TTL (Transistor Transistor Logic):

Logic level:

1 = +V

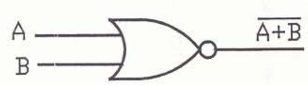
0 = 0V



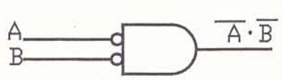
6-4 NOR Gate

The NOR gate is actually a NOT OR gate. In other words, the output of an OR gate is inverted to form a NOR gate. The unique output from the NOR gate is a HIGH only when all inputs are LOW. The output column of the Truth Table shows that only line 1 generates a 1 while all other outputs are 0. The Boolean expression, logic symbol and truth table are given below.

$$\overline{A+B} = C$$



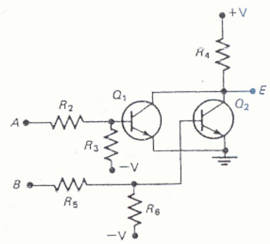
$$\overline{A+B} = \overline{A}\cdot\overline{B}$$



Inputs		Output
B	A	NOR
0	0	1
0	1	0
1	0	0
1	1	0

Practical Transistor Circuit

TTL (Transistor Transistor Logic):



The NOR gate includes a transistor for each input, as shown in the figure. Here the grouping of transistor Q_1 with resistors R_2, R_3, and R_4 is the same in the figure for NAND gate. In the NOR circuit, as input A rises to +V, transistor Q_1 turns on and the output at E goes near to 0 volts. Likewise, a positive voltage at input B turns Q_2 on, producing the same result at E. thus output E becomes 0 [false] when either A or B or both inputs are positive [true].

AND [symbol] Output is 1 only if all inputs are 1.

OR [symbol] Output is 0 only if all inputs are 0.

NAND [symbol] Output is 0 only if all inputs are 1.

NOR [symbol] Output is 1 only if all inputs are 0.

6-5 Exclusive OR Gate

Exclusive-OR is an interesting function, although less fundamental than AND and OR gates. The term "exclusive OR gate" is often shortened to "XOR gate". The output of an exclusive-OR gate is HIGH if one or the other (but not both) input is HIGH (it never has more than two inputs). Another way to say it is that the output is HIGH if the inputs are different. The XOR gate is sometimes referred to as the *any but not all gate*. Notice that in the Truth Table, if any but not all of the inputs are 1, then the output will be a binary, or logical, 1. The Boolean expression, logic symbol and truth table are given below.

Boolean equivalent:

$X = A \oplus B$

Also $X = (A + B) \cdot (\overline{A \cdot B})$

In words : A or B, but not both.

Inputs		Output
B	A	XOR
0	0	0
0	1	1
1	0	1
1	1	0

6-6 Exclusive NOR Gate

The term "exclusive NOR gate" is often shortened to "XNOR gate". In the Truth Table, please note that the output of the XNOR gate is the complement of the XOR gate. The Boolean expression, logic symbol and truth table are given below.

Boolean equivalent:

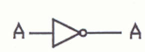
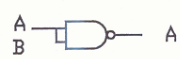
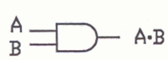
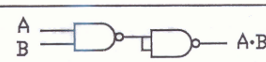
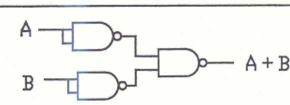
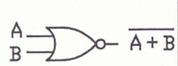
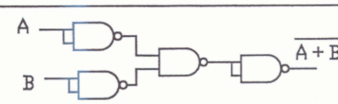
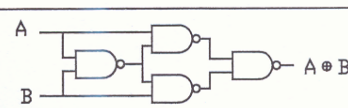
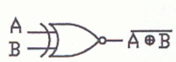
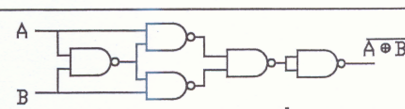
$$X = \overline{A \oplus B} \quad \text{Also } X = (A \cdot B) + (\overline{A} \cdot \overline{B})$$

In words: This is an equality detector, that is, it is true if and only if A = B.

Inputs		Output
B	A	XNOR
0	0	1
0	1	0
1	0	0
1	1	1

6-7 NAND Gate as a Universal Gate

Previously we have learned the basic building blocks used in digital circuits. We have learned about 7 types of gate circuits. Now we will see that NAND gate can be used to make other types of gates. The following figure shows how we would wire NAND gates to create any of the other basic logic functions. So NAND gate is a sort of *universal gate*.

Logic Function	Symbol	Circuit using Nand Gates only
Inverter		
AND		
OR		
NOR		
XOR		
XNOR		

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APPENDIX-A

CALCULUS

Integral:

If $F'(x) = f(x)$ for all x in some interval. Then $F'(x)$ is said to be an integral of f(x) in that interval.

Example:

$\frac{1}{4}x^4$ is an integral of x^3.

or $\int x^3 = \frac{x^{3+1}}{3+1} = \frac{1}{4}x^4$

Definite Integral

The expression $\int_a^b f(x)dx$ is called a definite integral and *a*, *b* its lower and upper limits respectively.

Example:

$$\int_1^2 x^2 dx = \left[\frac{x^3}{3}\right]_1^2 = \frac{2^3}{3} - \frac{1^3}{3} = \frac{8}{3} - \frac{1}{3} = \frac{7}{3}$$

Some **Standard Formulae**:

1) $\int(\sin x)dx = -\cos x$,

2) $\int(\sin^2 x)dx = \frac{1}{2}x - \frac{1}{4}\sin 2x$

rms (R.M.S.) value means

root e.g. $\sqrt{4} = 2$, mean $\left[\text{e.g. } \bar{x} = \frac{x_1 + x_2 + x_3}{3} \text{ or } \bar{\theta} = \frac{\int_0^{2\pi} d\theta}{2\pi}\right]$ & square e.g. $3^2 = 9$

Example:

$$i_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i^2 d\theta}$$